LODGEPOLE PINE CLEARCUT SIZE AFFECTS MINIMUM TEMPERATURES NEAR THE SOIL SURFACE

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INTRODUCTION

Large openings in several-aged lodgepole pine (*Pinus contorta* Dougl.) stands on flat topography in the pumice soil region of south-central Oregon are often hard to regenerate. As an example, a 7.4-acre clearcut, made in this type of lodgepole stand in 1938 on the Pringle Falls Experimental Forest, has not regenerated and seedling establishment in the opening has been restricted to a narrow area adjacent to the stand edge. Many other such cases occur within approximately one-half million acres of lodgepole pine growing on the Deschutes, Winema, and Fremont National Forests.

There are several possible reasons for this regeneration problem. Animal damage to seedlings may be an important factor. Many types of small animals, especially pocket gophers (*Thomomys talpoides*), tend to congregate and feed in these openings.

Seed dispersal can be inadequate. Lodgepole pine cones in this region open and shed their seed promptly following ripening, and there are adequate seed crops in at least 3 out of every 4 years. However, the number of seeds dispersed into clearcut areas falls off rapidly as distance from the stand edge increases and reaches a very low level at distances beyond 3 chains.[1/]

Heat injury and drought may cause some mortality. Lodgepole pine seedlings are abundant in many clearcuts on undulating or slightly sloping topography. In these situations, cold air has less tendency to accumulate at night than it does on flat areas, which suggests that low rather than high temperatures near the soil surface hinder lodgepole pine establishment in pumice soils.

Frost heaving, also a problem in parts of the pumice soil region, appears to cause the most damage in areas where amounts and patterns of snow accumulation create bare areas between drifts in the early spring.

In addition to the foregoing factors, severe night frosts during germination may be a significant cause of lodgepole pine seedling mortality. Berntsen[2/] found in laboratory experiments that lodgepole pine seedlings were killed during their germination period by night minimum temperatures of 13° F. (-10.6° C.). Field observations indicate several-aged lodgepole stands are naturally perpetuated by regeneration of small openings created by mortality of small groups of trees or single old trees. The plentiful natural regeneration in these small, partially protected openings and the lack of natural regeneration at distances greater than about 1 chain (one tree height) from the stand edge in several large clearcuts further indicate that low temperature may be a cause of regeneration problems.

Low night temperatures are common during the growing season in the pumice soil region of Oregon. Near Chemult, Oregon, the likelihood of

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[1] *Dahms, Walter G. Dispersal of lodgepole pine seed into clearcut patches. Pacific Northwest Forest & Range Exp. Sta. U.S.D.A. Forest Serv. Res. Note PNW-3, 7 pp., illus. 1963.*

[2] *Berntsen, Carl Martin. Relative low temperature tolerance of lodgepole and ponderosa pine seedlings. 158 numb. leaves. 1967. (Unpublished Ph.D. thesis on file at Oregon State Univ., Corvallis.)*

frost is greater than 50 percent on any summer night.[3] At least four factors contribute to this high frequency of night frost: (1) high altitude, (2) preponderance of clear nights, (3) a relatively dry airmass, and (4) the unique thermal properties of pumice soils. Pumice soils have much lower thermal diffusivities and much lower thermal contact coefficients at comparable water contents than other mineral soils of greater density, so wide surface temperature variations may be expected.[4] Thermal properties of pumice soils closely resemble those of peat soils on which frost hazards to crops have long been recognized.[5]

Lodgepole pine stands are commonly harvested by the strip clearcut method. If low temperatures are a problem in lodgepole pine regeneration, it is important to know how width of the cutting strip affects minimum temperatures near the soil surface.

MATERIALS AND METHODS

On a clear night, the open soil surface radiates more energy outward toward the sky in the form of longwave radiation than the sky radiates downward. The resulting net loss of energy causes the soil surface to cool rapidly, and very low minimum surface temperatures become possible. The net radiation flux for any particular spot on the soil surface within a forest opening during a clear, windless night is determined largely by the relative amount of radiation it receives from a "cold" sky and a "warm" tree canopy. This proportion can be represented by a geometric concept called the view factor.

The view factor is the fraction of radiation leaving a surface in all directions that is intercepted by another surface.[6] Of concern here is the view factor of a spot on a horizontal surface relative to the open sky. The greater the view factor for a particular spot, the more closely the net radiation flux of that spot will resemble the net radiation flux of a similar surface in a completely open area under the same meteorological conditions.

View factors were calculated for circular openings of various widths and for rectangular openings of various lengths and widths. View factors were also calculated for spots at various distances from the stand edge for very large clearcuts where the spots were influenced by only one stand edge. The equations used in these calculations and their derivations are given in the Appendix.

Minimum temperatures at 2.5 inches above the soil surface were determined at various distances from the edge of a clearcut in a several-aged lodgepole pine stand growing on flat topography on a Lapine pumice soil. Stand height is approximately 62 feet. The dimensions of the rectangular clearcut are

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[3] *Eichorn, N. D., Rudd, R. D., and Calvin, L. D. Estimating dates for low temperatures in Oregon, Corvallis. Oregon Agr. Exp. Sta. Bull. 581, 16 pp. 1961.*

[4] *Cochran, P. H., Boersma, L., and Youngberg, C. T. Thermal properties of a pumice soil. Soil Sci. Soc. Amer. Proc. 31:454-459. 1967.*

[5] *Wijk, W. R. van. Soil microclimate, its creation and modification. Meteorol. Monogr. 6(28):59-73, illus. 1965.*

[6] *Reifsnyder, William E., and Lull, Howard W. Radiant energy in relation to forests. U.S. Dep. Agr. Tech. Bull. 1344, 111 pp., illus. 1965.*

4.5 by 17.4 chains, with the long axis of the opening oriented in a north-south direction. The cut was made in 1938 and the soil surface in the opening is sparsely covered with grass; stumps, logs, and logging debris have largely disappeared. Temperatures were measured at the stand edge, 50 feet into the stand, and 50, 75, and 120 feet from the east edge of the stand in the opening. The measurement points were located on a transect perpendicular to the long axis of the opening.

Measurements were recorded with a data-logging system described elsewhere.[7] Thermistors were used as temperature sensors. Each thermistor was encased in a piece of polyvinyl chloride tubing which had been previously stretched in methyl-ethyl-ketone. After the tubing had shrunk around the thermistor, the assembly was dipped in epoxy resin to make a waterproof seal. The thermistor covering was then sprayed with white paint. The thermistors plus covering were approximately 1 cm. long and 0.25 cm. in diameter and had a resistance of 3,000 ohms at 25° C. with a tolerance of ± 1 percent. The thermistors were held at 2.5 inches above the soil surface by lead wires taped to the ends of L-shaped wires inserted into the ground.

Records were taken every 2 hours for periods of 1 to 2 days at approximately weekly intervals from May 30 to September 26, 1968. Recorders were started so that thermistor inputs were sensed just before sunrise to obtain minimum temperatures for the day. Hygrothermograph readings taken 2 miles from the study area indicated that minimum temperatures did occur just before sunrise for the days temperatures were recorded at the clearcut.

RESULTS AND DISCUSSION

View factors for circular openings are less than for strips of the same width (fig. 1). Thus, circular openings offer more protection against low soil-surface temperatures than long strips

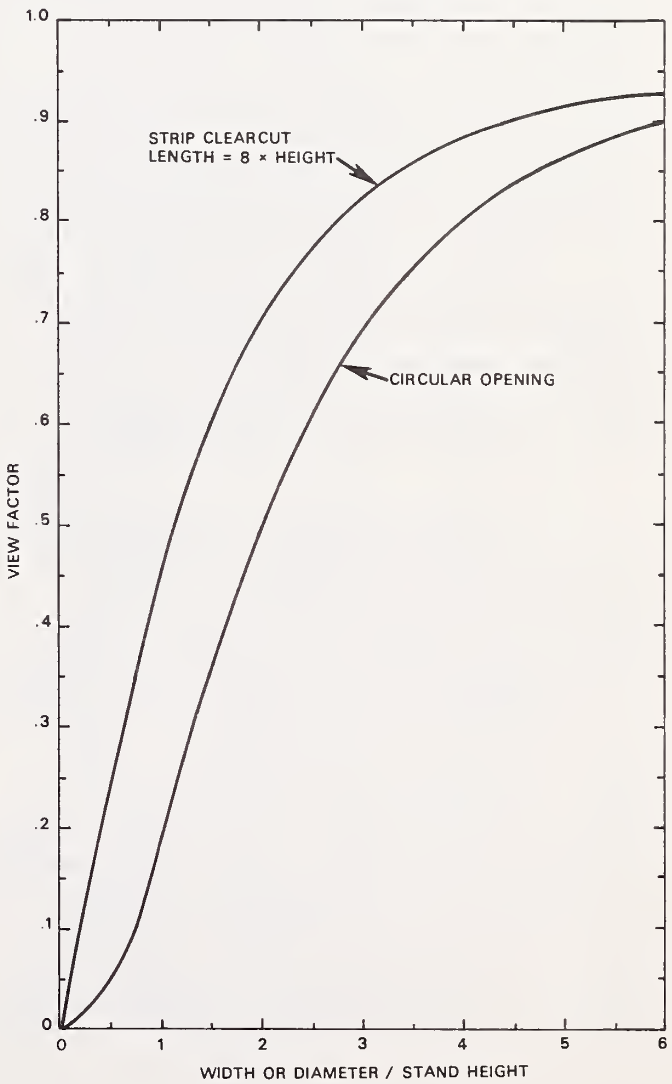

Figure 1.—View factor for the center of a rectangular and a circular forest opening as a function of opening width divided by stand height.

[7] *Cochran, Patrick Holmes. Heat and moisture transfer in a pumice soil. 165 numb. leaves. 1966. (Unpublished Ph.D. thesis on file at Oregon State Univ., Corvallis.)*

of the same width. On cold, clear, windless nights, when the sky has a lower effective temperature than the tree canopy, surface temperatures in strips will become lower than in circular openings of the same width. The soil surface in the center of the strip receives more radiation from the "cold" sky and less radiation from the "warm" tree canopy than does the center surface of the circular opening.

The view factor for the center of a long strip[8]--which is 4.5 times as wide as the stand height--is 0.9, indicating that the strip center is practically in the open. The view factor for the center of the circular opening does not reach 0.9 until the opening has a diameter 6 times the stand height. The low view factors for circular openings may explain why small, natural, circular openings in lodgepole pine stands usually have abundant natural regeneration, even when the stands are several aged on flat or depressional topography.

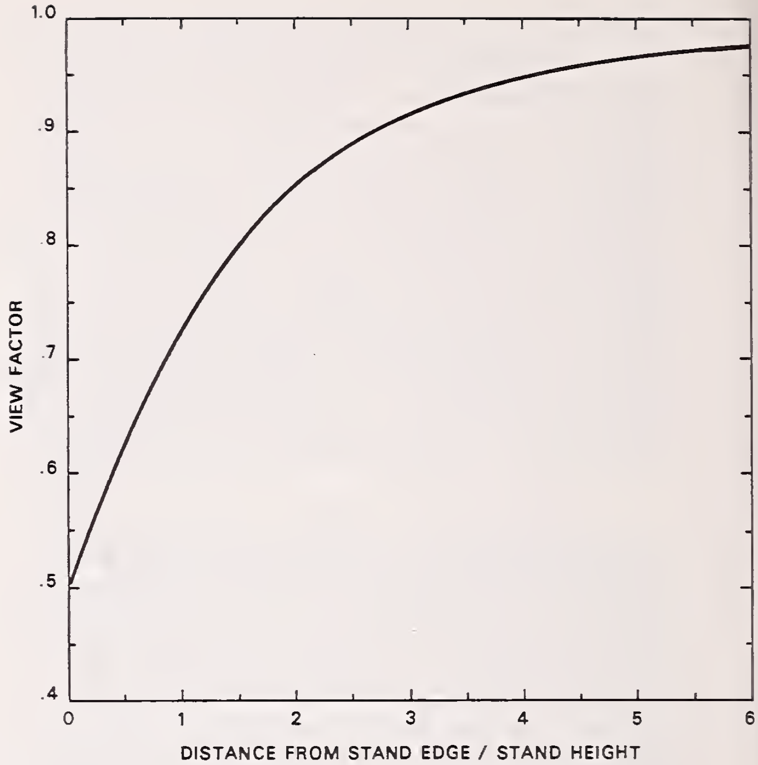

Figure 2.—View factor for spots on the soil surface in a very large rectangular opening as a function of distance from the stand edge divided by stand height.

Circular clearcuts are not practical in lodgepole pine management because small, irregularly shaped patches of timber would be created. These patches would eventually have to be logged and this operation would be inefficient. Therefore, strip or block clearcuts are employed. For large clearcuts, the protective influence of the stand edge tapers off rapidly with distance into the opening. For example, at a distance outward from the stand edge equal to stand height, the view factor is above 0.7 (fig. 2). At a distance outward equal to 3 times the stand height, the view factor is above 0.9. The minimum temperature averages also indicate that minimum temperatures decrease rapidly over a short distance outward from the stand edge (fig. 3). The data in figure 3 were taken after the germination period. During the germination period, the same pattern but lower temperatures may be expected. This minimum temperature pattern provides a possible explanation for the confinement of natural regeneration in some large clearcuts to outward distances approximately equal to stand height. Seed dispersal is adequate to greater distances,[9] so the absence of seedlings between 1 and 3 chains from the stand edge is not due to lack of seed.

Long clearcuts, wider than 4 to 6 times stand height, create essentially

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[8] *A long strip here is used to indicate any strip with a length greater than 8 times the height of the stand. For strips of any given width, the view factor for the strip center is not appreciably increased by increasing strip length beyond 8 times stand height.*

[9] *See footnote 1.*

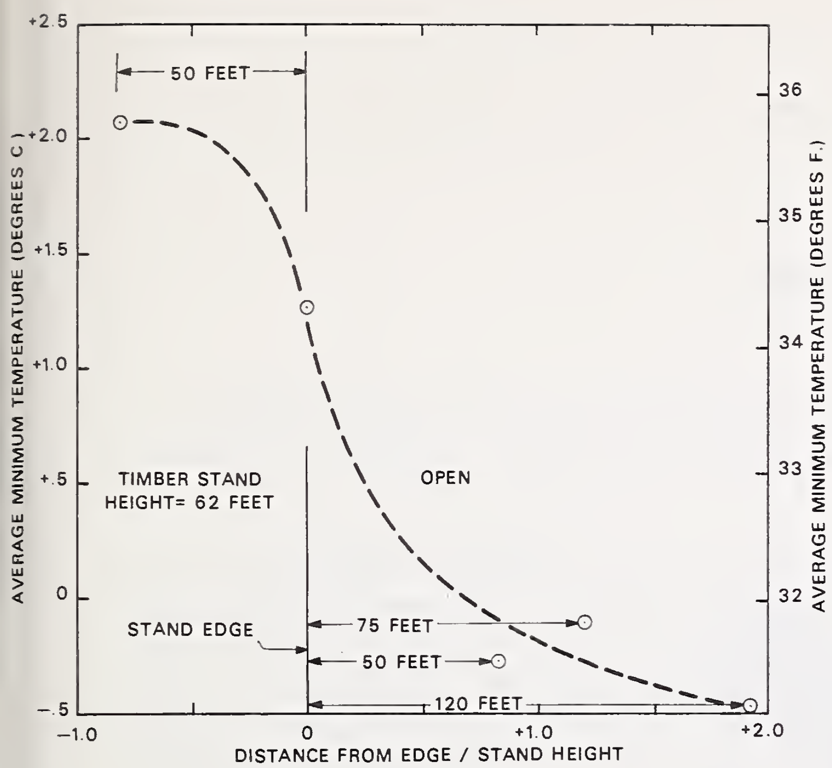

Figure 3.—Average minimum air temperatures at 2.5 inches above the soil surface for 18 days in a period starting May 30 and ending August 30, 1968. The dashed line is a freehand curve.

open areas toward the center of the strip. The moderating effect of the stand on minimum temperatures is insufficient to provide protection clear across the strip. Although the amount of protection necessary for lodgepole pine regeneration is not known, observations indicate a view factor of 0.7 or greater may result in minimum temperatures which are too low for newly germinated tree seedlings in problem areas. A problem area is regarded here as a several-aged lodgepole pine stand occurring on flat or depressional pumice-mantled topography. If this assumption is correct, prompt natural regeneration cannot be expected beyond a distance equivalent to tree height from the timbered edge in certain problem areas when widths of long strip clearcuts exceed three tree heights.

If natural regeneration is to be obtained in these problem areas, strip clearcuts should not be wider than twice the height of the stand. When other factors such as mistletoe control dictate that cutting strips in these problem areas must be wider than two tree heights, the center of the strip should be planted.

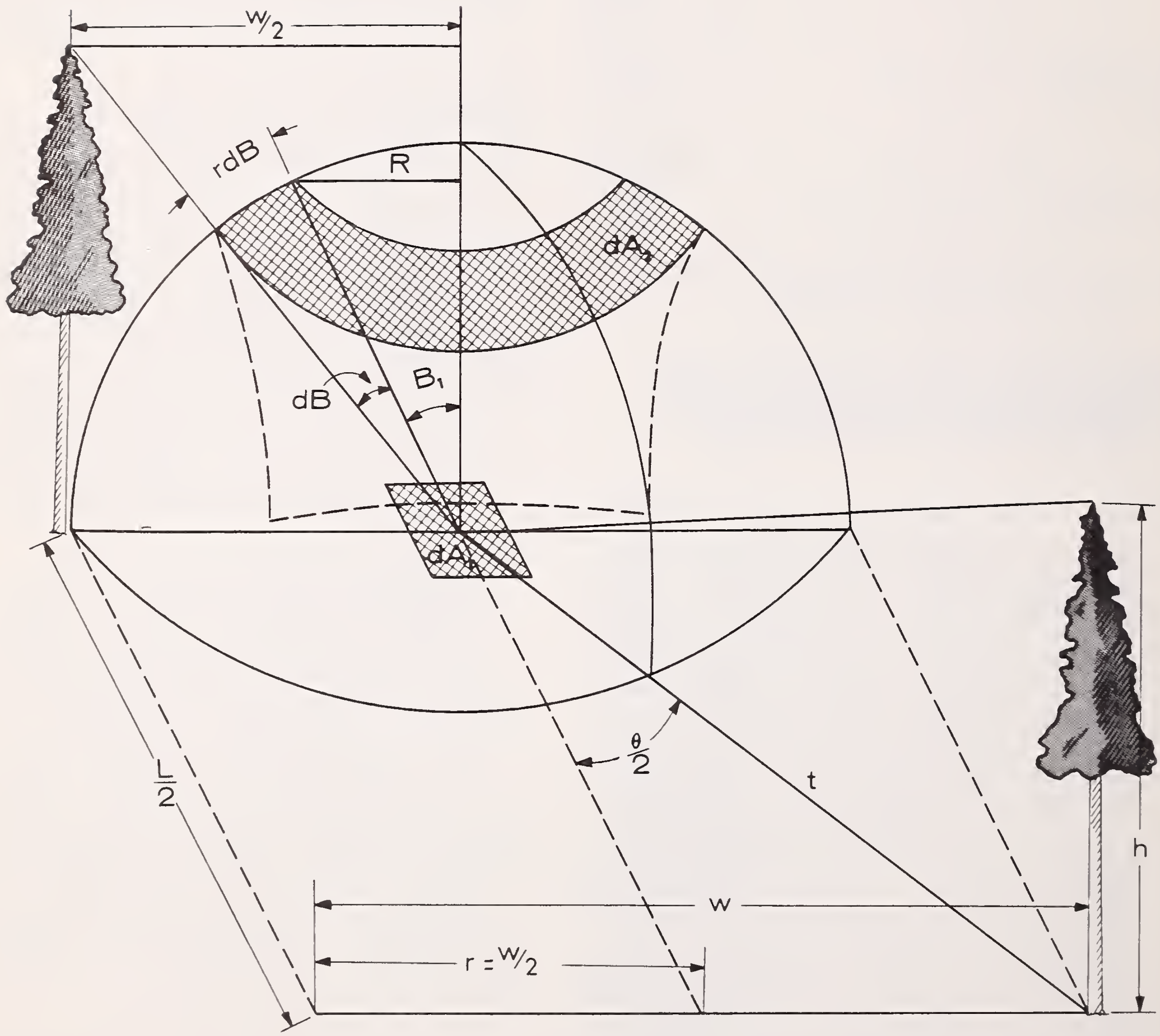

Figure 4.—Diagram used in the derivation of view factors for circular and rectangular forest openings. Area enclosed by dashed line represents that portion of the hemisphere open to the sky for a rectangular opening.

APPENDIX

Derivation of the view factor for a rectangular forest opening was accomplished by modification of and addition to the derivation of the view factor for a circular opening, presented by Reifsnyder and Lull (see footnote 6).

Consider an opening in tne forest of width (w) and length (L) surrounded by trees of height (h) (fig. 4). The sky above a small area, dA_1, in the center of the opening subtends a solid angle corresponding to arc tan ($w/2h$). A ray from dA_1 to the partial hemisphere of sky makes an angle, B_1, with the normal to dA_1 This ray meets the hemisphere at 90° angle. Therefore, B_2, the angle between the ray and the normal to the hemisphere at the point of intersection is 0°. The amount of radiation, dW, leaving dA_1 in the direction B_1 and intercepted by the surrounding hemisphere, is (see footnote 6):

$$dW_{1 \to 2}\text{ (sky)} = \frac{I_1 dA_1 \cos B_1 dA_2 \cos B_2}{r^2} \tag{1}$$

I_1 is the radiant flux density at dA_1 and $r = w/2$. The differential ring or ring segment, dA_2, is (see figure 4)

$$dA_2 = N\, RrdB$$

where N varies from 2π to 4 arc tan (w/L). Since $\cos B_2 = 1$, and $R/r = \sin B_1$, equation 1 becomes

$$dW_{1 \to 2}\text{ (sky)} = NI_1 dA_1 \sin B_1 \cos B_1 dB \tag{2}$$

For that portion of the hemisphere above the lower boundary of dA_2 as drawn in the figure, $N = 2\pi$ and B_1 varies from $B_1 = O$ to arc tan ($w/2h$). Integrating over this interval,

$$W_{1 \to 2}\text{ (sky)} = 2\pi\, I_1 dA_1 \int_{O}^{\text{arc tan } (w/2h)} \sin B_1 \cos B_1\, dB \tag{3}$$

$$= \pi\, I_1 dA_1 \sin^2 \left[\text{arc tan } (w/2h)\right] \tag{4}$$

For that portion of the hemisphere below the lower boundary of dA_2 as drawn in figure 1A, N=2 θ where θ is the angle between lines of sight from the center of dA_1 to the base of two trees directly opposite one another along the sides of the strip. Also, in this same portion of the hemisphere, B_1 is taken to vary from arc tan ($w/2h$) to arc tan ($L/2h$). B_1 actually becomes slightly larger than arc

tan $(L/2h)$ for the line of sight which extends from the center of dA_1 to the tree top at the corner of the rectangular opening. Since the interest here is in strips where L is several times w, the slight error introduced by use of arc tan $(L/2h)$ as the upper limit of B_1 is disregarded. θ varies with B_1 in the following manner:

$$t = h \tan B_1 ,$$

$$\sin \frac{\theta}{2} = \frac{w}{2h \tan B_1} ,$$

and

$$\theta = 2 \arcsin \left(\frac{w}{2h \tan B_1} \right)$$

Thus,

$$N = 2\theta = 4 \arcsin \left(\frac{w}{2h \tan B_1} \right)$$

Substitution of this value for N into equation 2 and integrating over the interval B_1 = arc tan $(w/2h)$ to arc tan $(L/2h)$ yields

$$W_{1 \to 2}\ (\text{sky}) = 4I_1\, dA_1 \int_{\arctan (w/2h)}^{\arctan (L/2h)} \arcsin \left(\frac{w}{2h \tan B_1} \right) \sin B_1 \cos B_1\, dB \tag{5}$$

For the entire hemisphere over dA_1,

$$W_{1 \to 2}(\text{total}) = 2\pi\, I_1 dA_1 \int_0^{\pi/2} \sin B_1 \cos B_1\, dB \tag{6}$$

$$= \pi\, I_1 dA_1 \left[\sin^2 B_1 \right]_0^{\pi/2}$$

$$= \pi\, I_1 dA_1 \tag{7}$$

The view factor, F_{1-2} of the sky relative to the spot dA_1, is defined as that portion of the total radiation leaving the spot that is directed toward the sky,

$$F_{1-2} = \frac{W_{1 \to 2}\ (\text{sky})}{W_{1 \to 2}\ (\text{total})} \tag{8}$$

$$= \frac{\pi\, I_1 dA_1 \sin^2 \left[\text{arc tan } (w/2h)\right]}{\pi\, I_1 dA_1}$$

$$+ \frac{4 I_1 dA_1}{\pi\, I_1 dA_1} \int_{\text{arc tan } (w/2h)}^{\text{arc tan } (L/2h)} \text{arc sin}\left(\frac{w}{2h \tan B_1}\right) \sin B_1 \cos B_1 dB \tag{9}$$

$$= \sin^2 \left[\text{arc tan } \left(\frac{w}{2h}\right)\right] + \frac{4}{\pi} \int_{\text{arc tan } \left(\frac{w}{2h}\right)}^{\text{arc tan } (L/2h)} \text{arc sin } \left(\frac{w}{2h \tan B_1}\right) \sin B_1 \cos B_1 dB \tag{10}$$

The first term on the right-hand side of equation 10 is the view factor for a circular opening of width or diameter w (Reifsnyder and Lull, see footnote 6). Equation 10 was evaluated with a digital computer for various widths and lengths expressed in multiples of tree height h.

View factors were also calculated for spots at various distances from the stand edge for very large clearcuts where the spots are influenced by only one stand edge. In this case, N in equation 2 varies from 2 π to θ^1 where θ^1 equals $2\left(\frac{\theta}{2}\right) + \pi$. B_1 varies from 0 to $\frac{\pi}{2}$ to arc tan $(w/2h)$ and $\frac{\theta}{2}$ can be expressed by arc sin $\left(\frac{w}{2h \tan B_1}\right)$.

Thus,

$$N = \theta^1 = 2 \text{ arc sin} \left(\frac{w}{2h \tan B_1}\right) + \pi$$

and equation 10 becomes

$$F_{1\to 2} = \sin^2 \left[\text{arc tan } \left(\frac{w}{2h}\right)\right] + \frac{2}{\pi} \int_{\text{arc tan } \left(\frac{w}{2h}\right)}^{\pi/2} \left[\text{arc sin } \left(\frac{w}{2h \tan B_1}\right) + \frac{\pi}{2}\right] \sin B_1 \cos B_1 dB \tag{11}$$

where w equals twice the distance from the stand edge and is expressed as a fraction or a multiple of tree height. Equation 11 was also evaluated with a digital computer.

Cochran, P. H.
1969. Lodgepole pine clearcut size affects minimum temperatures near the soil surface. U.S.D.A. Forest Serv. Res. Pap. PNW-86, 9 pp., illus. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

Low night temperatures may hinder the establishment of lodgepole pine seedlings in certain areas within the Oregon pumice soil region. Lodgepole stands in these problem areas are several aged and occur on flat or depressional topography. Sky exposures (view factors) for circular and rectangular openings were calculated, and minimum temperatures at 2.5 in. above the soil surface were determined at various distances from the stand edge for a large rectangular opening. If low night temperatures do limit seedling establishment, strip clearcuts in the problem areas should not be wider than twice the height of the stand. If other factors dictate wider strips in these problem areas, plans should be made to plant the strip centers.

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